Proceedings of the 2019 Winter Simulation Conference
N. Mustafee, K.-H.G. Bae, S. Lazarova-Molnar, M. Rabe, C. Szabo, P. Haas, and Y.-J. Son, eds.

ASSESSMENT OF THE IMPACT OF TELEDERMATOLOGY USING DISCRETE EVENT SIMULATION

Afafe Zehrouni
Vincent Augusto
Xiaolan Xie

MINES Saint Etienne
UMR CNRS 6158 LIMOS
158 Cours Fauriel
Saint Etienne Cedex 2, 42023, FRANCE

Tu-Anh Duong

Department of Dermatology
Hospital Henri Mondor
51 Av du Marchal de Lattre de Tassigny
Creteil, 94010, FRANCE

ABSTRACT

Evolution of technology and the complexity of the medical system have contributed to the increasing interest in telemedicine. The purpose of this paper is to present a discrete event simulation model of the teledermatology process using the tool TelDerm witch is a store-and forward tool linking health professionals with dermatologists for e-referrals. The logic of the simulation describes the process from the detection of the dermatological problem to its resolution. The scenarios reflect different changes in the flow in order to quantify the impact of telemedicine on the healthcare system. Several key performance indicators measure medical and administrative workload variations for all human resources involved. In addition, we assess the impact on the patients journey through the process.

1 INTRODUCTION

1.1 Context

Telemedicine is a form of remote medical practice using Information and Communication Technology. It connects, among themselves or with a patient, one or more health professionals. At least one medical professional is involved, and if needed a care provider. It uses the transmission by telecommunication of medical information (images, reports, recordings, etc.), in order to obtain a diagnosis, a specialized opinion, a continuous monitoring of a patient, or a therapeutic decision (as defined by World Health Organization).

In a context of considerable technological development, a decline in the number of specialists and the emergence of medical deserts, telemedicine provides a priori a complementary solution to facilitate access to care. In France, since 2018, the Social Security Financing Act offers the possibility of experimenting with new health organizations that are helping to improve patient care, the efficiency of the healthcare system and access to care. In addition, this law defines a compensation framework for the various acts of telemedicine, in order to better use new technologies to coordinate care between different users.

In this context, the chair "Avenir Santé Numérique" (Futur Digital Health) brings together a multi-disciplinary team combining skills from the academic world of health to that of the world of information technologies, as well as skills in economics and human sciences. The first axis of the Chair focuses on integrating telemedicine into the care system in several specialties. In this article, we present the work done for the dermatology specialty. The purpose is to elaborate a systemic evaluation of the TelDerm tool and its integration and scaling. TelDerm is a Store-and-forward tool open to health practitioners to request e-referrals from dermatological emergency dermatologists at Henri Mondor Hospital. Unlike e-consults, e-referrals do not include the patient (they are not directly in contact with the specialist). Store-and-forward

978-1-7281-3283-9/19/$31.00 ©2019 IEEE

or asynchronous telemedicine is collecting clinical information and sending it electronically to the dermatologists for evaluation. Information typically includes demographic data, medical history and image files. The health professional may use a desktop computer or a mobile device to gather and send the information. Information is transmitted by e-mail and uploaded to a secure server.

TelDerm has been deployed since 2014 and its use is increasing over the years. However, it remains very small compared to dermatological consultations in general, and consultations to dermatological emergencies in particular. The aim of the work presented is to quantify the impact of TelDerm and its evolution on the organization of healthcare systems and on the patient's journey. To this end, we are developing a discrete simulation model representing the current functioning of TelDerm and the predictions of its evolution. We measure indicators on different workloads induced by the use of telemedicine, as well as indicators on traveling times and waiting times for patients.

1.2 Related Research

The appearance of telemedicine in its current form dates back to the 1960s (Lee et al. 2000). Several researchers have since become interested in studying the therapeutic efficacy of telemedicine as well as its impact on the healthcare system. (Hailey et al. 2002) present a systematic review of telemedicine assessments between 1966 and 2000 that include comparison with a non-telemedicine alternative and that reported administrative changes, patient outcomes, and results of economic assessment.

There are several categories of telemedicine such as remote monitoring (remote interpretation of the data required for medical monitoring of a patient) or teleconsultations (allow a medical professional to consult a patient remotely). We focus in this literature review on the asynchronous telemedicine (also called telexpertise or store-and-forward telemedicine) defined as the aid to the diagnosis made to a doctor by another doctor through Information and Communication Technologies. (Deshpande et al. 2009) suggested that asynchronous telemedicine could result in shorter waiting times, fewer unnecessary referrals, high levels of patient and provider satisfaction, and equivalent (or better) diagnostic accuracy.

Teledermatology has been advocated as a mode of health care delivery that may diminish inequalities in the provision of an overstretched service and improve access to dermatological care, especially for remote or isolated communities (Eedy and Wootton 2001). Asynchronous teledermatology has several advantages according to previous studies. From a therapeutic point of view, it offers a high level of diagnosis accuracy most often comparable to face-to-face diagnosis (Baba et al. 2005). The impact of teledermatology is reflected in the care process by:

- The reduction of waiting times before consultations (Hockey et al. 2004),
- The ability to properly prioritize patients and the decrease of in-person visits (Knol et al. 2006),
- The decrease of consultations costs (Whited et al. 2002).

However, despite a large number of studies and systematic reviews on the effects of telemedicine, high quality evidence to inform policy decisions on how best to use telemedicine in health care is still lacking. Large studies with rigorous designs are needed to get better evidence on the effects of telemedicine interventions on health, satisfaction with care and costs (Ekeland et al. 2010).

Most studies are based on statistical studies of trials in teledermatology. The trials have been modest in size, data limited in size and conclusions as to the human dimensions that will be needed are still limited.

Discrete Event Simulation is widely used in the evaluation of the performance of the care system (Salleh et al. 2017). It allows inexpensive replication of existing systems or to implement and overcome limitations of statistical analysis on limited data. Discrete event simulation is suitable for health and care systems operation's evaluation. It enables health care managers to better understand how a system operates, and make optimal operational and administrative decisions (Zhang 2018). However, there is a lack of studies on quality improvements and on the cost-benefits associated with the introduction of ICT applications on health-care systems (Augusto et al. 2015). The application of simulation on the evaluation of telemedicine is fairly recent, and to our knowledge, very limited. In (Lach and Vazquez 2004), a simulation model is used to evaluate an e-consult program in Mexico. Using a mobile unit, patients are connected to a physician located in Mexico City through a satellite connection. The simulation model presented in (Jean 2015) evaluates the impact of telemedicine on the larger healthcare system. Both e-consults and asynchronous telemedicine are considered in the study. (Aeschliman 2015) outlines a simulation analysis of synchronous and asynchronous telemental health systems and (Swan et al. 2018) a simulation evaluation of e-consults in rheumatology.

1.3 Scientific contributions

In our paper, we use a discrete event simulation model to evaluate a teledermatology program integrated in the dermatological emergencies. The unique functioning of the structure is studied in order to quantify its current impact on the care system as well as its future evolution. Our performance indicators quantify both changes in the working time of the practitioners involved and changes in the patient's care path. The paper is organized as follows: first we present the functioning of the teledermatology tool TelDerm and the dermatological emergency service in which it is integrated. Then we present the logic of the simulation model and the resources considered. Finally, we present for several scenarios the key performance indicators measured as well as their analysis.

2 TELEDERMATOLOGY IN HOSPITAL HENRI MONDOR (FRANCE): CASE STUDY

Since 2004, access to dermatologists requires consultation with the general practitioner beforehand. The latter writes a letter specifying the dermatological problem as well as the clinical history of the patient. In 2014, the average waiting time between making an appointment with the dermatologist and consultation is 50 days, with great variability between regions. In some regions, there is a phenomenon called "medical desert", where the medical supply of specialists is not sufficient for the population of the region. This problem is not limited to France, and affects several countries worldwide.

Hospital Henri Mondor is part of the hospital group AP-HP (Assistance Publique Hopitaux de Paris) and offers a dermatological emergency (D.E) service unique in France. A dermatologist is available 24 hours a day, 7 days a week and 365 days a year. This service is accessible to any patient, walk-in or referred by another health professional, without making an appointment. Two dermatologists manage the service during business hours, and one during the night. Each consultation is recorded in the computerized patient file, and the report printed and given to the patient but rarely sent to the referring physician. A second event may take place after the consult if the dermatological problem is not solved or needs a follow up.

Between 2000 and 2010, the number of consultations in dermatological emergencies increased by 21% and the majority was walk-in patients. In addition, thanks to the widespread access to smart-phones, several physicians collaborate with dermatologists of D.E by phone (for summarizing the case of the patient) and mail or MMS (for sending photos).

Since 2014, a teledermatology service (TelDerm) has been integrated into dermatological emergencies (Duong 2016). TelDerm is a store-and-forward application based on collecting photos and clinical information and sending it electronically to the on call dermatologist at Henri Mondor. Therefore, this application is only accessible to health professionals, whether they are general physicians, belong to another health facility or to accommodation facility for dependent elderly people EDE (Estalishment for dependent elderly). The availability of dermatologists 24h/24 in the service of dermatological emergencies ensures a rapid response for urgent patients (less than 2 hours), otherwise a notice is given within a few hours. If the quality of the e-referral is not sufficient to render a medical opinion, the dermatologist may request new photos or more details about the patient. If not, the dermatologist responds to the referral in writing, and records the consultation on secure computer support. Patients are not automatically called, if they need a face to face consult they are given an appointment at the D.E (Duong 2016).

Figure 1 presents the source of the consultations carried out in the dermatological emergencies, as well as the second event that follows the consultation at the D.E or the e-referral (Drahy 2018).

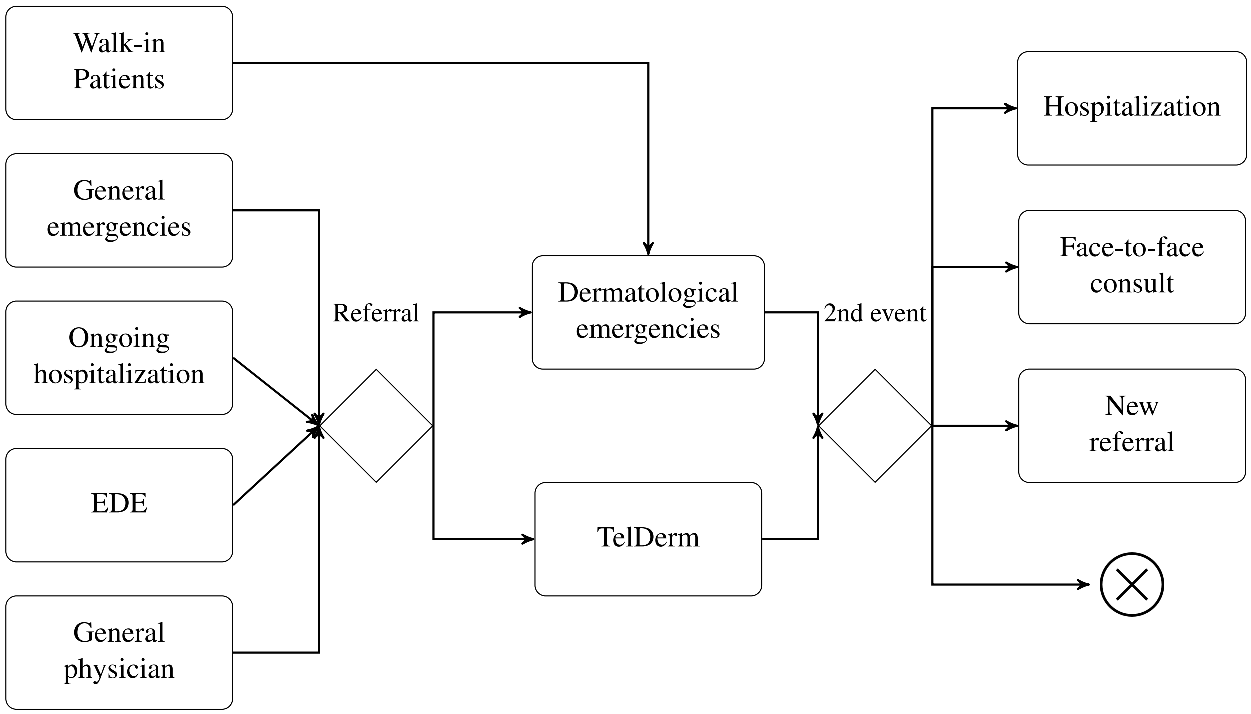

Figure 1: Source of consultations in dermatological emergencies.

3 SIMULATION MODEL

The structure of TelDerm can be described as a star network, called Hub & Spoke, where the central node is represented by the team of dermatologists and the secondary nodes represent the different referring doctors. This structure allows the process to be taken into account from the detection of the dermatological problem in the patient to the resolution of the referral. The modeling of the teledermatology process TelDerm consists in representing on the one hand the various resources considered and on the other hand the process of using these resources to meet the medical objectives. This modeling is the basis of our process and must represent as accurately as possible the reality of the process

3.1 Teledermatology Key Resources

We consider as resources in our modeling all the human resources that ensure the consultations in dermatological emergencies. The process of teledermatology requires an insignificant material investment, since access to the software is free and requires either a smartphone or a computer (almost always available). Any use of the TelDerm tool for an e-referral requires at least two main resources: the referring general practitioner and the dermatologist who responds to the request. Both have medical and administrative workload. The administrative responsibilities related to the teledermatology process can mostly be provided by medical secretaries, but not all practitioners and institutions dispose of medical secretaries and doctors are then responsible for all administrative tasks. In addition, like any computer tool, there is a risk of problems related to access (connection and sending files, for example). The intervention (remote or on site) of a technical team is then necessary to unlock access. The human resources that we consider in our model are:

1. The referring physician (Spoke): establishes referrals and takes photos of the patients. When the dermatologist gives his opinion, the referring doctor is responsible for forwarding the recommendations to the patient. We group in this category all general physicians regardless of their institutions (private or hospitals).
2. The dermatologist (Hub): reviews requests and photo files accompanying them. If the information is sufficient to make a medical opinion, the dermatologist prepares a report including the recommendations for the patient (face-to-face consultation, care plan,...).
3. The administrative team (hub and spoke): performs administrative tasks related to the backup of referrals and answers from dermatologists, as well as the sending of the care plan to referring practitioner.
4. The technical team (hub and spoke): controls computer access to the TelDerm tool, and performs interventions in case of technical problems.

3.2 Simulation Logic

The objective of the simulation is to evaluate the impact of the integration of TelDerm in the D.E. The process starts with the detection of the dermatological problem. The first step for the patient is then to seek a consultation either at the dermatological emergencies or the referring doctor. It should be noted that we group under referring practitioners all practitioners presented in Figure 1. Consultation in dermatological emergencies leads to a plan of care or the resolution of the problem. The consultation with the referring doctor results in either a referral to dermatological emergencies or an e-referral. To carry out the e-referral, the doctor must connect to the TelDerm platform, fill in the patient's information and attach the patient's photos. At the reception of the e-referral, the dermatologist present in the dermatological emergencies analyzes the patient's medical file as well as the photos. Finally, they write a recommendation of care plan for the patient. Sometimes the e-referral lacks information or the quality of the photos is insufficient. The dermatologist makes a request to the referring physician to modify the e-referral. The referring physician then sends the report to the patient, and the two physicians archive the e-referral in the patient's file.

Figure 2 summarizes the consultation process in dermatological emergencies, using TelDerm or not, for the two main resources (referral physician and dermatologist) and the patient. The blue blocks represent the medical burden of the referring doctor and the dermatologist. The red blocks represent the administrative steps that can be performed by the medical secretaries or, failing that, the referring doctor or dermatologist. Finally, the green blocks represent the stages where there is a risk of computer failure, and therefore require the intervention of the technical team (hub and spoke).

3.3 Key Performance Indicators

The objective of the simulation model is to evaluate the impact of the integration of the TelDerm tool on the organization of the D.E. The use of TelDerm is increasing but still represents a small percentage of the D.E consultations. With this predicted evolution, the key performance indicators to be measured aim to evaluate the impact of TelDerm on the workload of the referring practitioners and dermatologists on one hand, and on the care of the patient on the other hand. Table 1 summarizes the key performance indicators and associated notations.

The indicator W_{DE} measures TelDerm's potential impact on patients waiting time for a dermatological emergency consultation. This can be a direct effect of the change of workload of the on-call dermatologist. The indicator W_{cp} measures the total time of the patient in the system, that is to say the time between the detection of the dermatological problem and the reception by the patient of the treatment plan. When patients go the the D.E instead of using the e-referral tool TelDerm, T_{de} measures the mean traveling time for the face-to-face consult.

For both hub and spoke structures, we measure the medical workload of dermatologists and referring doctors (Med_h and Med_s respectively), the administrative workload that may be done by doctors or secretaries

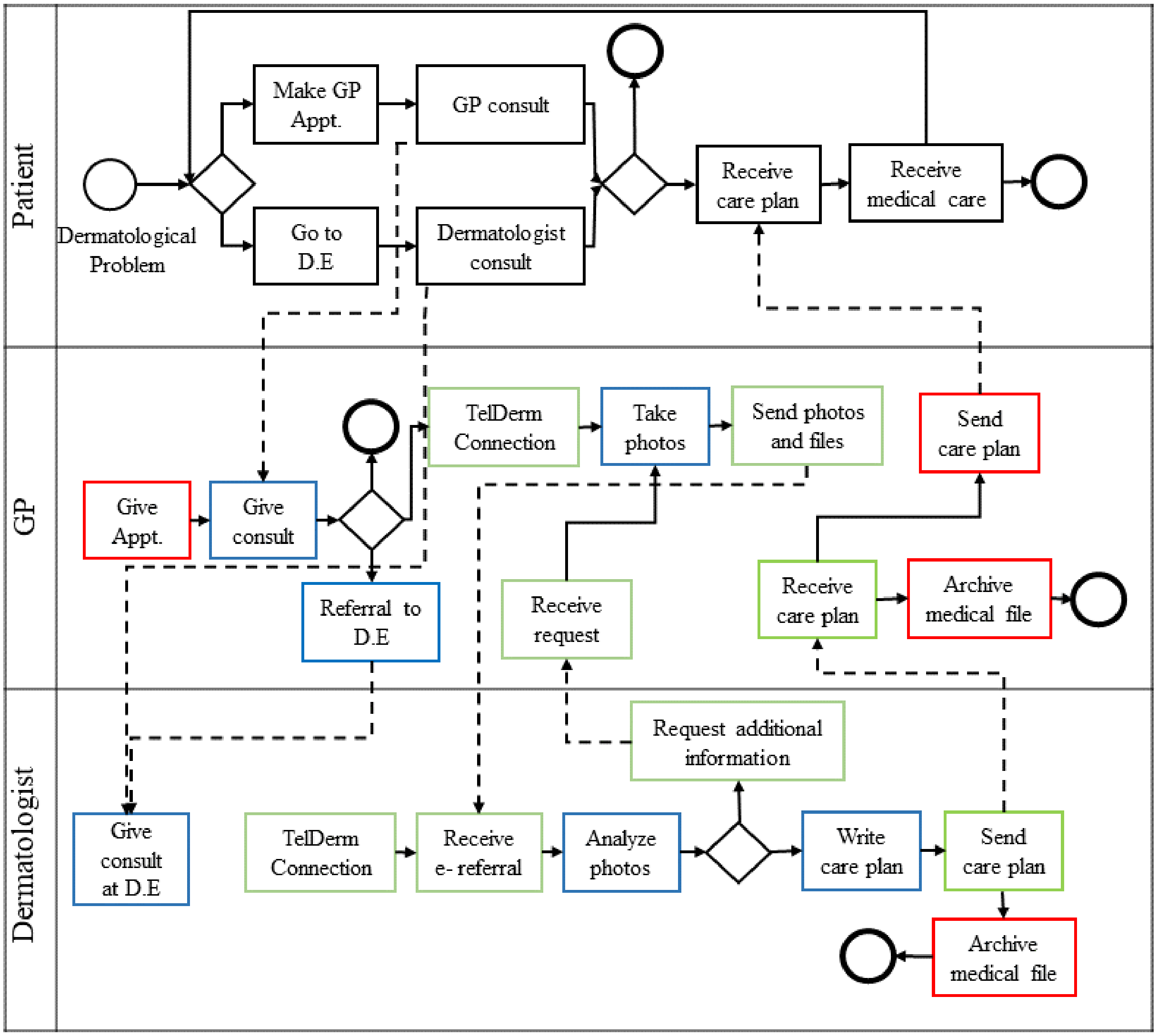

Figure 2: Process of consult at the dermatological emergencies including TelDerm.

(Adm_h and Adm_s). As we introduce a probability of connection or computer problems, we measure the technical workload in both hub and spoke ($Tech_h$ and $Tech_s$).

4 DATA AND RESULTS

The simulation model presented in this paper is made using the AnyLogic software. The simulation follows the logic presented in Section 3.2 using the actual data from TelDerm. Nevertheless, the data remain limited and we use probabilistic distributions in the different scenarios.

4.1 Initial Data and Probabilistic Distributions

70% of patients receiving a dermatological emergency consultation are walk-in patients. For referrals, practitioners choose to send patients to the D.E or use the TelDerm tool to get the opinion of the dermatologist. We do not have exact data on the percentage of referrals via TelDerm. We will use this information in the development of simulation scenarios.

Table 1: Key performance indicators.

Category	Indicator	Notation
Patient indicators	Waiting time at D.E	W_{DE}
	Waiting time for a care plan	W_{cp}
	Traveling time to the D.E	T_{de}
Hub resource utilization	Medical workload of dermatologist	Med_h
	Administrative workload	Adm_h
	D.E workload	$D.E_h$
	Technical workload	$Tech_h$
Spoke resource utilization	Medical workload of referring physician	Med_s
	Administrative workload	Adm_s
	D.E referrals workload	$D.E_s$
	Technical workload	$Tech_s$

(Drahy 2018) presents the source of referrals to D.E and e-referrals via TelDerm calculated on a sample of the consultations (Table 2). As we observe, the majority of referrals to dermatological emergencies come from a general practitioner (70.1%) while the majority of e-referrals come from general emergencies (42.8%) and other institutions where patients are already hospitalized (21.1%). In addition, 13% of patients who received e-referrals are subsequently called for a face-to-face consultation at the D.E.

Table 2: Pourcentage of referral and e-referral sources.

Source	D.E (%)	TelDerm (%)
Emergency room	23.6	42.8
Ongoing hospitalization	4.2	34
EDE	2.1	2.1
General physician (GP)	70.1	21.1
Total	100	100

From data collected at the hospital Henri Mondor, we represent the durations of the different tasks of the process by a triangular distribution. The parameters are summarized in Table 3. In addition, we consider the waiting time for an appointment at the general practitioner is around 3 days ($triangular(1,4,3)$). Waiting times at the D.E are represented by a triangular distribution as well, and it's median is 1h07minutes with a minimum of 2 minutes and a maximum of 4 hours. Fot the arriving rate of patients, we use Poisson distributions with various means as scenario criteria.

4.2 Simulation Scenarios

The scenarios presented in this section are intended to cover several possibilities of evolution of TelDerm in the health care system.

For the results we present in the next section, we consider four evolution scenarios with the first scenario $S0_S$ that is based on the data collected in 2018. These scenarios vary in:

- Number of face-to-face consultations at the D.E: includes walk-in patients and the referrals.
- Number of e-referrals: representing the patients referred from other medical institutions and general practitioners using TelDerm,
- Maximum travel distance: represents in hours the maximum time traveled for a face-to-face consult at the D.E for the patients, and for an e-referral for the medical practitioners,
- Rate of referral: patients presenting themselves to EDs

Table 3: Referring practitioner and dermatologist's workload distributions by process phase.

Resource	Phase	Triangular distribution parameters (in minutes)		
		minimum	maximum	median
Referring practitioner (spoke)	Connection	0	30	1
	Medical file	3	7	4
	Photos	2	20	4
	Send e-referral	1	4	2
	Receive response	2	5	3
Dermatologist (hub)	Connection	0	30	1
	Analysis	1	5	3.5
	Care plan	1	4	2
	Archiving	2	8	5
	Consult at D.E	10	25	18

Scenario $S1_S$ represents the evolution of demand but with the percentage of e-referrals unchanged compared to 2018 (scenario $S0_S$). Scenario $S2_S$ represents the increase in demand as well as the use of e-referrals via TelDerm. Scenario $S3_S$ represents the scenario where e-referrals are accepted by patients and physicians, so the rate of patient self-referral decreases and the likelihood of physicians using TelDerm instead of the classical referral increases. Table 4 summarizes the scenarios and there parameters. In addition, scenarios $S0_L$ to $S3_L$ use the same data as the scenarios $S0_S$ to $S3_S$ with the exception of the maximum travel distance which goes to 4h (Large zone).

Table 4: Scenarios data for a maximum travel distance of 2 hours.

Data	$S0_S$	$S1_S$	$S2_S$	$S3_S$
Total number of consults	23500	47000	47000	47000
Number of face-to-face consults at D.E	20000	40000	35000	35000
Number pf e-referrals	3500	7000	11000	11000
Maximum travel distance	2 hours	2 hours	2 hours	2 hours
Rate of referrals	30%	30%	30%	50%

4.3 Results and Discussion

Each scenario is simulated over a period of one year and replicated 1000 times. The following results are the average of the replications. The impact of the maximum travel distance is mainly reflected on the patient indicators. For the sake of readability, we present for the other KPI for the scenarios $S0_S$ to $S3_S$ taking into account the current maximum travel distance (2 hours).

4.3.1 Hub and spoke workload KPI

For the workload indicators of the spoke physicians and hub specialists, we represent the results in full-time equivalent. An FTE of 1.0 is equivalent to a full-time worker, and according to French legislation corresponds a weekly workload of 48 hours for doctors, 35 hours for tech and administrative workers.

In the current configuration of TelDerm (scenario $S0_S$), the medical load to provide care is 2.59 FTE (2.17 to D.E and 0.42 to e-referrals). This shows a work overload of the two FTE that manage the service. Added to this is the administrative workload related to e-referrals, which amounts to an average of 0.15

FTE, which corresponds to 15% of the working time of a dermatologist in the absence of a medical secretary and to (Figure 3).

The more the demand increases, the more the workload increases (Scenario $S1_S$). When the demand and the use of teledermatology increase (Scenario $S2_S$), the medical workload at the D.E decreases but the administrative workload increases. In the absence of a medical secretary, dermatologist time savings due to teledermatology are lost in administrative tasks. This conclusion is confirmed by scenario $S3_S$, where the use of TelDerm is better accepted by patients and physicians. In this scenario, 5.1 FTE provide the same number of consultations and e-referrals as the $S2_S$ instance (5.25 FTE). The administrative workload rises to 0.7 FTE (corresponding to 0.96 non-medical FTE).

From the referring physician's point of view (Figure 4), we observe that the medical and administrative workload of e-refferals is far superior to the classic referral. We do not know the number of referring physicians so it is difficult to reflect the impact of teledermatology on each practitioner. However, with the evolution of TelDerm, the associated workload is increasing (from 1.2 to 3 FTE for medical tasks, and from 0.2 to 0.7 FTE for administrative tasks). More data is needed to better evaluate the spoke KPI.

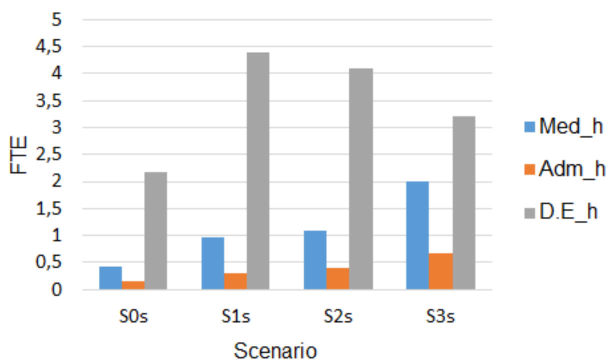

Figure 3: Hub KPI in full-time equivalent.

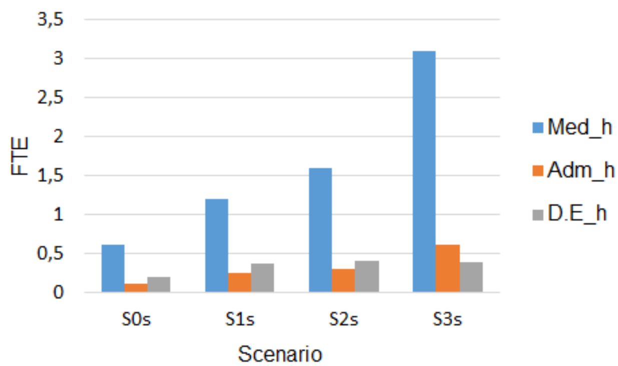

Figure 4: Spoke KPI in full-time equivalent.

Technical interventions are limited and do not require immediate recruitment decisions. The workload is equitably distributed between the hub and the spokes and ranges from 0.02 to 0.1 FTE depending on the scenario (Figure 5). These interventions can be entrusted to a remote repair service, or a medical employee can be trained to intervene on breakdowns.

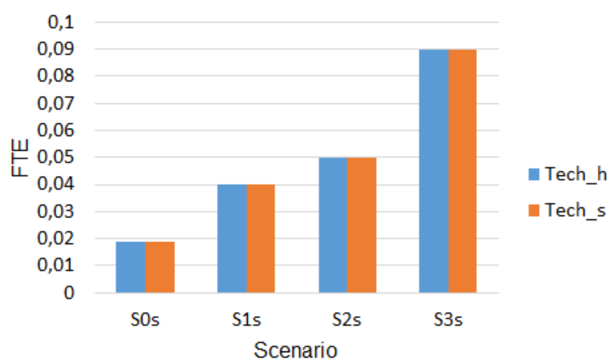

Figure 5: Tech KPI for a small service area.

4.3.2 Patient KPI

In the current situation, the average traveling time of patients to D.E is 48 minutes with a maximum travel distance of 2h (Figure 6). This duration increases with the expansion of the territory reaching 95 minutes, and decreases to 35 minutes with the development of e-referrals. The majority of patients travel by car or public transportation, but patients in EDE or in continuous hospitalization require transportation by medical vehicles. A more accurate analysis of patients will allow in future work to estimate the precise cost of patient transport.

Patient's mean waiting time at the D.E remains stable in response to the increase in demand and the maximum travel distance (around 80 minutes). This indicator then decreases for the scenarios $S2$ and $S3$, in particular because of the decrease in the number of face-to-face consultations at the D.E. This indicator needs to be more precise by considering a real queue with a limited number of dermatologists and a realistic arrival distribution.

The duration of the patient journey between detecting and resolving the dermatological problem is stable for different maximum travel distances and number of consultations (around 0.7 days). This indicator increases with the evolution of teledermatology until waiting for 0.96 days in average. This is mainly due to the waiting times for GP appointments, and does not include referrals from other medical institutions.

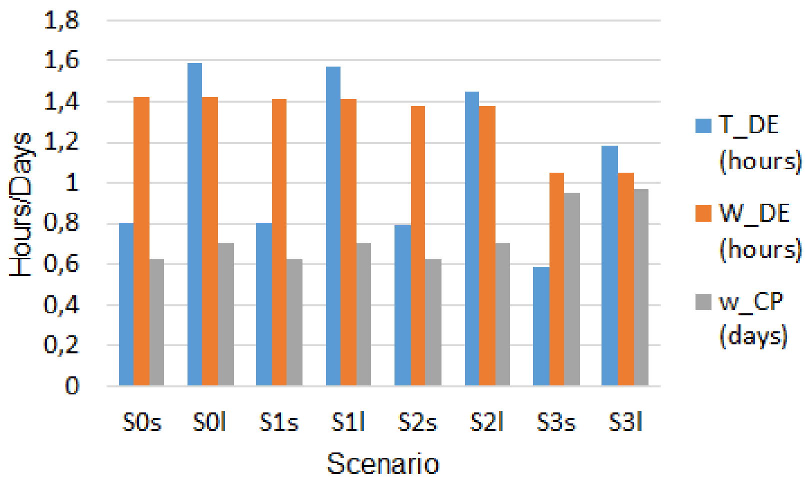

Figure 6: Patient KPI for small and large service area.

The scenarios tested in these results correspond to the current instance as well as several possible evolutions. All evolution scenarios consider an increase in demand with more or less acceptance of teledermatology. In all the results, we observe an organizational change for the professionals as well as for the patients which requires more attention from the decision-makers. If used properly, teledrmatology could allow a better organization of the work of the dermatologists and a better offer of care for the patients.

5 CONCLUSION

In this paper, we presented a simulation model for assessing the impact of integrating teledermatology into the healthcare system. Telemedicine is becoming increasingly important in the French healthcare system, and simulation is a powerful tool for understanding, analyzing and improving the changes needed for all the resources involved in telemedicine.

A major change in the functioning of physicians and specialists is the administrative workload of telemedicine. Decision-makers must choose between recruiting and / or centralizing administrative tasks in order to better utilize costly resources (general practitioners and dermatologists). This investment is important for the purpose of providing coordinated care and sharing and continuity of patients' medical records.

From the point of view of patients, one of the natural conclusions of the use of teledermatology is to reduce traveling times. Nevertheless, relative to the direct passage through dermatological emergencies, the duration of the patient's journey (from detection to resolution) increases with telemedicine.

In future work, we improve the quality of the indicators by a more detailed process, especially from the point of view of patients. We are working on social and human indicators as well as a medico-economic analysis (in collaboration with other researchers in the Avenir Sant Numrique chair). At the same time, we use the same methodology for other e-consultas and e-referrals formats in France whose functionality differ significantly from TelDerm (call-center for appointments, for example). The objective remains the decision support for the generalization of telemedicine practices throughout the territory.

REFERENCES

Aeschliman, R. 2015. *Modeling and Analysis of Telemental Health Systems with Petri Nets*. Ph.D. thesis, Kansas State University, Manhattan, Kansas.

Augusto, V., O. Rejeb, X. Xie, S. Aloui, L. Perrier, P. Biron, and T. Durand. 2015. "Performance Evaluation of Health Information Systems Using ARIS Modeling and Discrete-Event Simulation". In *Proceedings of the 2015 Winter Simulation Conference*, edited by L. Yilmaz, W. K. V. Chan, I. Moon, T. M. K. Roeder, C. Macal, and M. D. Rossetti, 1503–1514. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Baba, M., D. Seckin, and S. Kapdali. 2005. "A Comparison of Teledermatology Using Store-and-Forward Methodology Alone, and in Combination with Web Camera Videoconferencing". *Journal of Telemedicine and Telecare* 11(7):354–360.

Deshpande, A., S. Khoja, J. Gmez, A. McKibbon, C. Rizo, D. Husereau, and A. Jadad. 2009. "Asynchronous Telehealth: A Scoping Review of Analytic Studies". *Open Medicine : A Reer-Reviewed, Independent, Open-Access Journal* 3(2):69–91.

Drahy, F. 2018. *Recours Médicaux à l'Expertise Dermatologique Urgente : Consultation d'Urgence et Télédermatologie*. Ph.D. thesis, Université Paris Descartes, Paris, France.

Duong, T. 2016. *Intégration par les Usages dune Innovation en Santé : La Télédermatologie*. Ph.D. thesis, Université Paris-Saclay, Paris, France.

Eedy, D., and R. Wootton. 2001. "Teledermatology: a Review". *British Journal of Dermatology* 144(4):696–707.

Ekeland, A., A. Bowes, and S. Flottorp. 2010. "Effectiveness of Telemedicine: A Systematic Review of Reviews". *International Journal of Medical Informatics* 79(11):736–771.

Hailey, D., R. Roine, and A. Ohinmaa. 2002. "Systematic Review of Evidence for the Benefits of Telemedicine". *Journal of Telemedicine and Telecare* 8(1):1–30.

Hockey, A. D., R. Wootton, and T. Casey. 2004. "Trial of Low-Cost Teledermatology in Primary Care". *Journal of Telemedicine and Telecare* 10(1):44–47.

Jean, C. 2015. "Predictive Modelling of Telehealth System Deployment". *Journal of Simulation* 9(2):182–194.

Knol, A., T. van den Akker, R. Damstra, and J. de Haan. 2006. "Teledermatology Reduces the Number of Patient Referrals to a Dermatologist". *Journal of Telemedicine and Telecare* 12(2):75–88.

Lach, J. M., and R. M. Vazquez. 2004. "Simulation Model of the Telemedicine Program". In *Proceedings of the 2004 Winter Simulation Conference*, edited by R. G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters, 2012–2017. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Lee, S.-G., S. Mun, P. Jha, B. Levine, and D.-W. RO. 2000. "Telemedicine: Challenges and Opportunities". *J. High Speed Networks* 9(1):15–30.

Salleh, S., P. Thokala, A. Brennan, R. Hughes, and A. Booth. 2017. "Simulation Modelling in Healthcare: An Umbrella Review of Systematic Literature Reviews". *PharmacoEconomics* 35(9):937–949.

Swan, B., C. Shevlin, A. Cho, and D. Phinney. 2018. "Simulation Tool to Evaluate Electronic Consultations in Rheumatology". In *Proceedings of the 2018 Winter Simulation Conference*, edited by M. Rabe, A. A. Juan, N. Mustafee, A. Skoogh, S. Jain, and B. Johansson, 2589–2599. Piscataway, New Jersey: Institute of Electrical and Electronics Engineers, Inc.

Whited, J., R. Hall, M. Foy, L. Marbrey, S. Grambow, T. Dudley, S. Datta, D. Simel, and E. Oddone. 2002. "Teledermatology's Impact on Time to Intervention among Referrals to a Dermatology Consult Service". *Telemedicine Journal and e-Health: The Official Journal of the American Telemedicine Association* 8(3):313–321.

Zhang, X. 2018. "Application of Discrete Event Simulation in Health Care: a Systematic Review". *BMC Health Services Research* 18(1):687–698.

AUTHOR BIOGRAPHIES

AFAFE ZEHROUNI received her Ph.D. degree from the École Nationale Superieure des Mines de Saint-Étienne (EMSE), France, in 2016 in industrial engineering. Currently, she occupies a postdoctoral position in the Center for Health Engineering and in the IEOR team of CNRS UMR 6158 LIMOS, EMSE. Her research interests include operational research, modeling and simulation. Her email adress is afafe.zehrouni@emse.fr.

VINCENT AUGUSTO received his Ph.D. in Industrial Engineering from Mines Saint-Etienne, France, in 2008 and the Habilitation Diriger des Recherches degree from the University of Saint -Etienne, France, in 2016. He was a visiting scholar at CIRRELT (Centre Interuniversitaire de Recherche sur les Rseaux dEntreprise, la Logistique et le Transport), University of Laval, Quebec, Canada in 2009 and 2015. Currently, he is a professor of industrial engineering in the Department of Health care Engineering at Mines Saint-Etienne. His research interests include modeling, simulation, optimization of health care systems and their supply chains, process mining and machine learning applied to health-care. His e-mail address is augusto@emse.fr.

TU ANH DUONG is a dermatologist graduated from the University of Paris in 2012. She obtained a PhD in Industrial Sciences and Technologies at the University of Paris Saclay in 2016. In 2014, she launched the TelDerm tool to offer e-referrals to other healthcare professionals and better organize consultations at Henri Mondor Hospital, where she currently works as a dermatologist. She is responsible for the Avenir Sant Numrique chair, launched in 2018, and which includes the works presented in this article.

XIAOLAN XIE received his Ph.D degree from the University of Nancy I, Nancy, France, in 1989, and the Habilitation à Diriger des Recherches degree from the University of Metz, France, in 1995. Currently, he is a distinguished professor of industrial engineering, the head of the department of Healthcare Engineering of the Center for Health Engineering and the head of IEOR team of CNRS UMR 6158 LIMOS, Ecole Nationale Supérieure des Mines (ENSMSE), Saint Etienne, France. He is also a chair professor and director of the Center for Healthcare Engineering at the Shanghai Jiao Tong University, China. He is author/coauthor of over 250 publications including over 90 journal articles and five books. He has rich industrial application experiences with European industries. He is PI for various national and international projects including ANR-TECSAN HOST on management of winter epidemics, NSF China key project on planning and optimization of health care resources, French Labex IMOBS3 project on home health cares, FP6-IST6 IWARD on swarm robots for health services. His email address is xie@emse.fr.